CLAIMS:

1. A method for determining the maximum and minimum horizontal stresses of formations surrounding a borehole, comprising the steps of:

suspending a logging device in the borehole;

transmitting sonic energy from said logging device to establish flexural waves in the formations;

receiving, at said logging device, sonic energy from said flexural waves, and producing, from the received sonic energy, measurement signals at a number of frequencies;

determining, at said number of frequencies, the fast and slow flexural wave velocities in the formations, to obtain fast and slow flexural velocity dispersions;

establishing a model of formation stresses in which stresses of a loaded state are represented by the sum of an omnidirectional hydrostatically loaded mean reference stress, a vertical stress perturbation, and maximum and minimum horizontal stress perturbations;

establishing an inversion model that includes inputs from said fast and slow flexural velocity dispersions and also includes unknown horizontal perturbations of said model of formation stresses;

deriving, from said inversion model, estimates of said maximum and minimum horizontal stress perturbations; and

determining, from said estimates of said maximum and minimum horizontal stress perturbations and said mean reference stress, estimates of the maximum and minimum horizontal stresses of said formations.

2. The method as defined by claim 1, further comprising the step of determining stress coefficients of the fast and slow flexural velocities as a function of frequency, and using said determined stress coefficients to obtain an estimate of said vertical stress perturbation.

3. The method as defined by claim 2, further comprising determining said mean reference stress using the overburden stress, the stress due to pore pressure, and said obtained estimate of the vertical stress perturbation.

4. The method as defined by claim 3, wherein said step of determining estimates of the maximum and minimum horizontal stresses of the formations includes, respectively, adding said determined mean reference stress to said maximum horizontal stress perturbation and adding said determined mean reference stress to said minimum horizontal stress perturbation.

5. The method as defined by claim 4, wherein said step of determining estimates of the maximum and minimum horizontal

stresses of the formations further includes adding pore pressures in the determination of said maximum and minimum horizontal stresses of the formations.

6. The method as defined by claim 2, further comprising deriving a reference flexural velocity dispersion, and wherein said determination of said estimate of the vertical stress perturbation also depends on said reference flexural velocity dispersion.

7. The method as defined by claim 3, further comprising deriving a reference flexural velocity dispersion, and wherein said determination of said estimate of the vertical stress perturbation also depends on said reference flexural velocity dispersion.

8. The method as defined by claim 5, further comprising deriving a reference flexural velocity dispersion, and wherein said determination of said estimate of the vertical stress perturbation also depends on said reference flexural velocity dispersion.

9. The method as defined by claim 6, wherein said step of establishing an inversion model comprises establishing said inversion model as including differences between said fast and slow flexural velocity dispersions, normalized by said reference flexural velocity dispersion.

10. The method as defined by claim 8, wherein said step of establishing an inversion model comprises establishing said inversion model as including differences between said fast and slow flexural velocity dispersions, normalized by said reference flexural velocity dispersion.

11. The method as defined by claim 9, wherein said step of deriving a reference flexural velocity dispersion includes determining said reference flexural velocity dispersion from an assumed isotropic and homogeneous formation model.

12. The method as defined by claim 10, wherein said step of deriving a reference flexural velocity dispersion includes determining said reference flexural velocity dispersion from an assumed isotropic and homogeneous formation model.

13. The method as defined by claim 11, further comprising deriving measured monopole compressional and shear velocities, and deriving said assumed isotropic and homogeneous formation model using said measured monopole compresssional and shear velocities.

14. The method as defined by claim 12, further comprising deriving measured monopole compressional and shear velocities, and deriving said assumed isotropic and homogeneous formation

model using said measured monopole compresssional and shear velocities.

15. The method as defined by claim 2, wherein said step of deriving, from said inversion model, estimates of said horizontal perturbations, further comprises deriving, from said inversion model, normalized formation stiffness constants.

16. A method for determining isotropic horizontal stresses in a shale interval of formations surrounding a borehole, comprising the steps of:

(a) suspending a logging device in the borehole;

(b) transmitting sonic energy from said logging device to establish flexural waves in the formations;

(c) receiving, at said logging device, sonic energy from said flexural waves, and producing, from the received sonic energy, measurement signals at a number of frequencies;

(d) determining, at said number of frequencies, the flexural wave velocities in the formations, to obtain a flexural velocity dispersion;

(e) performing the steps (a) through (d) at vertically spaced apart upper and lower depth levels in said shale region to obtain upper and lower flexural velocity dispersions;

(f) establishing models of formation stresses at said upper and lower depth levels in which stresses of a loaded state

are represented by the sum of an omnidirectional hydrostatically loaded mean reference stress, a vertical stress perturbation, and a horizontal stress perturbation;

(g) establishing inversion models that include inputs from said upper and lower flexural velocity dispersions and also includes unknown vertical and horizontal perturbations of said model of formation stresses at said upper and lower depth levels;

(h) deriving, from said inversion models, estimates of said vertical and horizontal stress perturbations at said upper and lower depth levels; and

(i) determining, from said estimates of said vertical and horizontal stress perturbations at said upper and lower depth levels and said mean reference stress, estimates of the horizontal stress at the upper and lower depth levels in said shale interval of said formations.

17. The method as defined by claim 16, further comprising the step of determining stress coefficients of the flexural velocities at said upper and lower depth levels as a function of frequency, and using said determined stress coefficients to obtain an estimate of said vertical stress perturbation at said upper and lower depth levels.

18. The method as defined by claim 17, further comprising determining, at said upper and lower depth levels, said mean

reference stress using the overburden stress, the stress due to pore pressure, and said obtained estimate of the vertical stress perturbation.

19. The method as defined by claim 18, wherein said step of determining, at said upper and lower depth levels, an estimate of the horizontal stress of the formations includes, respectively, adding said determined mean reference stress to said horizontal stress perturbation at said upper depth level and adding said determined mean reference stress to said horizontal stress perturbation at said lower depth level.

20. The method as defined by claim 19, wherein said step of determining, at said upper and lower depth levels, an estimate of the horizontal stress of the formations further includes adding pore pressures in the determination of said horizontal stress of the formations.

21. The method as defined by claim 17, further comprising deriving a reference flexural velocity dispersion, and wherein said determination of said estimates of the vertical and horizontal stress perturbations at said upper and lower depth levels also depends on said reference flexural velocity dispersion.

22. The method as defined by claim 21, wherein said step of establishing inversion models comprises establishing said inversion models as including differences between said upper and lower flexural velocity dispersions, normalized by said reference flexural velocity dispersion.

23. The method as defined by claim 22, wherein said step of deriving a reference flexural velocity dispersion includes determining said reference flexural velocity dispersion from an assumed isotropic and homogeneous formation model.

24. The method as defined by claim 23, further comprising deriving measured monopole compressional and shear velocities, and deriving said assumed isotropic and homogeneous formation model using said measured monopole compresssional and shear velocities.

25. For use in conjunction with a technique for investigating formations surrounding an earth borehole that includes the steps of: suspending a logging device in the borehole; transmitting sonic energy from said logging device to establish flexural waves in the formations; receiving, at said logging device, sonic energy from said flexural waves, and producing, from the received sonic energy, measurement signals at a number of frequencies; and determining, at said number of

frequencies, the fast and slow flexural wave velocities in the formations, to obtain fast and slow flexural velocity dispersions; a method for determining the maximum and minimum horizontal stresses of the formations, comprising the steps of:

establishing a model of formation stresses in which stresses of a loaded state are represented by the sum of an omnidirectional hydrostatically loaded mean reference stress, a vertical stress perturbation, and maximum and minimum horizontal stress perturbations;

establishing an inversion model that includes inputs from said fast and slow flexural velocity dispersions and also includes unknown horizontal perturbations of said model of formation stresses;

deriving, from said inversion model, estimates of said maximum and minimum horizontal stress perturbations; and

determining, from said estimates of said maximum and minimum horizontal stress perturbations and said mean reference stress, estimates of the maximum and minimum horizontal stresses of said formations.

26. The method as defined by claim 25, further comprising the step of determining stress coefficients of the fast and slow flexural velocities as a function of frequency, and using said determined stress coefficients to obtain an estimate of said vertical stress perturbation.

27. The method as defined by claim 26, further comprising determining said mean reference stress using the overburden stress, the stress due to pore pressure, and said obtained estimate of the vertical stress perturbation.

28. The method as defined by claim 27, wherein said step of determining estimates of the maximum and minimum horizontal stresses of the formations includes, respectively, adding said determined mean reference stress to said maximum horizontal stress perturbation and adding said determined mean reference stress to said minimum horizontal stress perturbation.

29. The method as defined by claim 28, wherein said step of determining estimates of the maximum and minimum horizontal stresses of the formations further includes adding pore pressures in the determination of said maximum and minimum horizontal stresses of the formations.

30. The method as defined by claim 26, further comprising deriving a reference flexural velocity dispersion, and wherein said determination of said estimate of the vertical stress perturbation also depends on said reference flexural velocity dispersion.

31. The method as defined by claim 30, wherein said step of establishing an inversion model comprises establishing said inversion model as including differences between said fast and slow flexural velocity dispersions, normalized by said reference flexural velocity dispersion.

32. The method as defined by claim 31, wherein said step of deriving a reference flexural velocity dispersion includes determining said reference flexural velocity dispersion from an assumed isotropic and homogeneous formation model.

33. The method as defined by claim 32, further comprising deriving measured monopole compressional and shear velocities, and deriving said assumed isotropic and homogeneous formation model using said measured monopole compresssional and shear velocities.

34. The method as defined by claim 26, wherein said step of deriving, from said inversion model, estimates of said horizontal perturbations, further comprises deriving, from said inversion model, normalized formation stiffness constants.

35. For use in conjunction with a technique for investigating formations surrounding an earth borehole that includes the steps of:

(a) suspending a logging device in the borehole; (b) transmitting sonic energy from said logging device to establish flexural waves in the formations; (c) receiving, at said logging device, sonic energy from said flexural waves, and producing, from the received sonic energy, measurement signals at a number of frequencies; (d) determining, at said number of frequencies, the flexural wave velocities in the formations, to obtain a flexural velocity dispersion; a method for determining isotropic horizontal stresses in a shale interval of the formations, comprising the step of:

(e) performing the steps (a) through (d) at vertically spaced apart upper and lower depth levels in said shale region to obtain upper and lower flexural velocity dispersions;

(f) establishing models of formation stresses at said upper and lower depth levels in which stresses of a loaded state are represented by the sum of an omnidirectional hydrostatically loaded mean reference stress, a vertical stress perturbation, and a horizontal stress perturbation;

(g) establishing inversion models that include inputs from said upper and lower flexural velocity dispersions and also includes unknown vertical and horizontal perturbations of said model of formation stresses at said upper and lower depth levels;

(h) deriving, from said inversion models, estimates of said vertical and horizontal stress perturbations at said upper and lower depth levels; and

(i) determining, from said estimates of said vertical and horizontal stress perturbations at said upper and lower depth levels and said mean reference stress, estimates of the horizontal stress at the upper and lower depth levels in said shale interval of said formations.

36. The method as defined by claim 35, further comprising the step of determining stress coefficients of the flexural velocities at said upper and lower depth levels as a function of frequency, and using said determined stress coefficients to obtain an estimate of said vertical stress perturbation at said upper and lower depth levels.

37. The method as defined by claim 36, further comprising determining, at said upper and lower depth levels, said mean reference stress using the overburden stress, the stress due to pore pressure, and said obtained estimate of the vertical stress perturbation.

38. The method as defined by claim 37, wherein said step of determining, at said upper and lower depth levels, an estimate of the horizontal stress of the formations includes, respectively, adding said determined mean reference stress to said horizontal stress perturbation at said upper depth level and adding said

determined mean reference stress to said horizontal stress perturbation at said lower depth level.

39. The method as defined by claim 38, wherein said step of determining, at said upper and lower depth levels, an estimate of the horizontal stress of the formations further includes adding pore pressures in the determination of said horizontal stress of the formations.

40. The method as defined by claim 36, further comprising deriving a reference flexural velocity dispersion, and wherein said determination of said estimates of the vertical and horizontal stress perturbations at said upper and lower depth levels also depends on said reference flexural velocity dispersion.

41. The method as defined by claim 40, wherein said step of establishing inversion models comprises establishing said inversion models as including differences between said upper and lower flexural velocity dispersions, normalized by said reference flexural velocity dispersion.

42. The method as defined by claim 41, wherein said step of deriving a reference flexural velocity dispersion includes determining said reference flexural velocity dispersion from an assumed isotropic and homogeneous formation model.

43. The method as defined by claim 42, further comprising deriving measured monopole compressional and shear velocities, and deriving said assumed isotropic and homogeneous formation model using said measured monopole compresssional and shear velocities.